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A report on the destruction of
3-Quinuclidinyl benzilate (BZ)

1. Introduction

In June 1986, the United States presented to the Conference on Disarmament a document outlining the United States Chemical Stockpile Disposal Program (CD/711). That document described the United States intent to dispose of its agent BZ stocks at Pine Bluff Arsenal, Arkansas. In June 1990, the United States completed the destruction of BZ and BZ-related materials, ending a 13-year project that cost $US 162.9 million. The following describes the BZ destruction program.

2. General overview

Agent BZ (3-quinuclidinyl benzilate) is an odourless, white crystalline solid which, when ingested, disturbs the functions of memory, comprehension, deduction and attention. The Army purchased 100,000 pounds of BZ in the early 1960s and produced two air deliverable weapons at Pine Bluff Arsenal (PBA): the M43 Cluster Bomb and the M44 Generator Cluster. The BZ was blended into a smoke mix and loaded into small canisters which were clustered into the weapons.

In August 1976, the United States Army Toxic and Hazardous Materials Agency (now the Office of the Program Manager for Chemical Demilitarization) was directed to develop a program for the destruction of the approximately 1,500 BZ munitions and about 10,000 pounds of pure BZ left over from the manufacturing operations. In addition, about 637 tons of contaminated residue from the manufacturing operations, cleanup of a storage igloo fire, and the testing operations associated with the initial process development, were to be destroyed.

A four phase program for the demilitarization of the BZ inventory was initiated in August 1977. The first phase consisted of laboratory development and verification of a viable destruction process. This phase was concluded in June 1981 with the selection of the incineration process. Phase two involved the design of the equipment and facilities required for the support of the selected process. It was completed in June 1982. Phase three consisted of the construction of the plant, acquisition and installation of the plant equipment, as well as systemization of the plant process. Plant systemization was completed by March of 1988. In May of 1988, phase four, plant operations, began. By September of 1989 all of the BZ munitions and agent in the PBA inventory had been destroyed. All remaining BZ contaminated residue at PBA was detoxified/incinerated by January of 1990. Plant cleanup and closure was completed in June of 1990. A timeline at Figure 1 chronicles the major milestones of the BZ demilitarization.

3. Inventory description

The BZ inventory items that were demilitarized, decontaminated and/or destroyed at the BZ facility are shown in Table 1, "BZ Munition & Items Inventory". The major items include M43 Cluster Bombs, M44 Generator Clusters, neat BZ, and drums containing solids and liquids. The dimensions and configurations of each BZ munition, and related containers are shown in Figures 2 through 4. Descriptions of each of the munitions and items that were stored at PBA follow:

(a) The M43 Cluster Bomb contained 57 M138 bomblets, which were arranged in three stacks of 19 each, separated by fibreboard spacers. Each bomblet was a thin walled steel cylinder containing four canisters and equipped on one end with an impact fuse. Each canister was filled with a 50/50 agent-pyrotechnic mixture. After separation from the cluser, the bomblet would immediately arm. Upon impact the fuse actuated and after an 8 to 12 second delay the pyromix ignited. Each cluster bomb was packed in a shipping guard constructed of eight wood stringers and two wooden end pieces secured by 1-1/4" steel strapping. Two clusters were overpacked in a plywood box as a security cover.

(b) The M44 Generator Cluster consisted of three BZ smoke generators stacked end-to-end in the cluster. Each smoke generator contained three tiers of 14 canisters and was equipped with a parachute assembly and a time delay

fuse. Each M44 was packaged individually in a plywood box measuring 56-3/4" long by 17-1/8" wide by 18-1/2" high, equipped with a fibreboard cover. The box was anchored to three skids.

(c) The neat, or bulk, BZ inventory was packed in 16-gallon steel drums. Each drum was lined with a polyethylene bag and contained 15 to 70 pounds of BZ (average weight of 45 pounds). Each 16-gallon steel drum was overpacked in a 30-gallon polyethylene bag and sealed inside a 30-gallon steel drum.

(d) Most solid and liquid residues were contained in 55-gallon steel drums. Solid residues consisted of contaminated scrap metal, clothing, tools, metal parts, refrigerator equipment, wood crating materials, downloaded canisters and miscellaneous solid materials. The liquid residue consisted of contaminated ion-exchange resin, liquid from sumps, and liquid decontamination residue. A significant number of the drums containing liquid residue had developed leaks over the years, and these "leakers" were placed in commercial 85-gallon overpack drums.

(e) There were six open top bins, approximately 24 cm long by 84 cm wide by 94 cm high, containing cut-up metal parts, tools, PVC pipe, and other miscellaneous items from the cleanup of the BZ pilot plant.

(f) In addition to the original Pine Bluff inventory, 42 BLU-50/B23 bombs were also processed at the BZ facility. These bombs were small, 40 gram munitions with a BZ/pyromix cast in a resin inside a canister the size of a D-cell battery. These were experimental munitions that were never placed into production.

In all, this inventory represents approximately 721 tons of material that was thermally detoxified at the BZ facility. The munition inventory included approximately 157,000 submunitions and 95,000 pounds of BZ agent. This total does not include the plant generated wastes which were processed concurrently during operations.

4. Method selection

(a) Two alternative methods of destruction of the BZ munitions were identified and examined early in the BZ disposal program: chemical neutralization and incineration.

(b) The first method considered was sodium hydroxide-based neutralization. A study completed in July 1980 concluded that BZ could be destroyed by base hydrolysis and that operating parameters and destruction

rate data were sufficiently quantified to permit, with reasonable confidence, the preliminary design of a full-scale chemical destruction process. However, the following inherent drawbacks were identified in the neutralization process that would affect its application in a full-scale facility:

(1) The destruction efficiency of BZ is limited in the neutralization process, particularly at high initial BZ concentrations.

(2) The presence of high concentrations of organic compounds and salts in the residual liquid present a potential disposal problem.

(3) The solution generated during the process is unstable and tends to increase in viscosity with time.

(c) These problems necessitate that the aqueous mixture generated by the neutralization process be incinerated to ensure destruction of the BZ and effective disposal of the organic chemicals. This two-step destruction process was not regarded as cost-effective, particularly when initial laboratory results had already indicated that the BZ and BZ/pyromix could be destroyed by one step incineration.

(d) Subsequent testing of the incineration process for the destruction of BZ indicated the following results:

(1) Bench scale incineration of neat BZ, BZ/pyromix, or BZ-contaminated material at 1,000° C for two seconds in excess air achieved destruction efficiencies at or greater than the target level of 99.994 per cent destruction.

(2) Decontamination at 1,000° C for 30 minutes of BZ-contaminated metal, glass, chars and residues in bench scale units reduced the BZ content below detection limits.

(3) Pyrolysis of BZ or BZ/pyromix at 500° C for two seconds achieved destruction near the target level, although extensive formation of tar-like products occurred.

(e) Thus, the direct one-step incineration process was chosen over the chemical neutralization method for application to the full-scale facility.

5. Environmental concerns

In the process of selecting a method for the destruction of the BZ inventory, the Office of the United States Army Program Manager for Chemical Demilitarization prepared documentation of potential environmental impacts that could occur during the construction and operation of a demilitarization facility. This documentation is required by the Natural Environmental Policy Act, as well as other Federal, State and local regulating

and permitting agencies. The primary environmental document was the Environmental Assessment prepared in August of 1983. The environmental assessment discussed the construction and operation aspects of a proposed facility and evaluated the associated environmental impacts. Several environmental considerations are identified and examined. The following list outlines the major topics:

(a) Alternatives considered:
    (1) Process alternatives
    (2) Location alternatives

(b) Description of the affected environment:
    (1) Air quality and climatology
    (2) Water resources and water quality
    (3) Geological resources
    (4) Land use
    (5) Socio-economic resources
    (6) Existing acoustic environment
    (7) Transportation
    (8) Cultural/historical/archaeological resources
    (9) Ecological resources
    (10) Threatened and endangered species

(c) Environmental impacts of the proposed action:
    (1) Air quality
    (2) Water quality
    (3) Soil and hazardous waste disposal impacts
    (4) Geologic hazards
    (5) Land use impacts
    (6) Transportation
    (7) Socio-economic
    (8) Health impacts
    (9) Noise impacts
    (10) Cultural/historical/archaeological resources impacts
    (11) Ecological resources impacts
    (12) Threatened and endangered species impacts

The conclusion of the evaluation was that the proposed action was not expected to significantly affect the quality of the human environment, did not set a precedent for other United States Army actions, and therefore, did not necessitate the preparation of an Environmental Impact Statement.

6. Process selection/description

(a) Once incineration was selected for destruction of the BZ and BZ-related materials, the next step was to define a process by which we could implement the incineration method in full-scale plant operations. After considering several options, a process was accepted that consisted of unpacking and rendering inert (by water soaking under pressure) the munitions, disassembling the munitions to their component parts (submunitions) and destroying the agent-containing submunitions in a rotary Deactivation Furnace System (DFS). Metal parts, wood dunnage and contaminated residues would be processed through a metal parts furnaces. The discharged material from the metals parts furnaces would be land-filled at an approved site. A liquids incinerator would be used to destroy the neat BZ, which was dissolved in acetic acid. Agent contaminated liquids, wash down liquids and toxic area shower waters were also to be destroyed in the liquids incinerator.

(b) After the process was determined and the site selected, the facility design and construction was initiated. The resulting BZ facility at Pine Bluff covers nearly 10 acres and consists of several structures.

(c) The main processing area of the BZ facility is the Munitions Demilitarization Building (MDB). The MDB houses the materials handling, munitions disassembly and thermal processing equipment used to demilitarize the BZ inventory.

(1) The toxic change area within the MDB contains storage for various levels of protective clothing and equipment, change areas, personnel showers, suit removal areas, monitoring stations and decontamination showers.

(2) The Munitions Inerting Room (MIN) contained four free-standing steel inerting vessels and support equipment where munitions were inerted by soaking them in water under pressure. Evacuating the air from the munition and injecting water to ensure contact with the pyrotechnic mixture enabled safe handling of the munitions.

(3) A rotary DFS contained within a heat protective shroud in a steel reinforced concrete room was a key element of the BZ facility. Together, the furnaces of the DFS burned out and decontaminated the

submunitions from the BZ munitions. Scrap discharged from the DFS entered a heated discharge conveyor (HDC) which was located adjacent to the furnace room.

(4) The Metal Parts Furnace (MPF) System consisted of a total of four natural gas fired furnaces in a sealed, ventilated room. The MPFs were used to thermally decontaminate an assortment of inventory and plant-generated waste items. Two of the four MPFs had primary fume burners attached to their exhaust stacks to enable them to process certain Resource Conservation and Recovery Act (RCRA) hazardous waste.

(5) The liquid incinerator and several liquid collection holding tanks were housed in the liquid incinerator room (LIC). All plant liquid process waste from inerting the munitions, daily and weekly wash downs, and the acetic acid solution containing the neat BZ, were pumped to and destroyed in the LIC.

(6) A chemical distribution system was the central location for storage, preparation and distribution of acetic acid and decontamination solutions used throughout the BZ facility.

(7) The exhaust from each of the furnace systems was ducted to a common afterburner. The final effluent was processed through a bag house to catch any residual particulate and the clean gases were then monitored and exhausted through a 40 metre stack. An agent alarm during operations would cause feed to the furnaces to be suspended if agent was detected.

(8) Air monitors were placed in several locations in the MDB during operations to monitor the BZ levels and the levels of several compounds specified by the industrial hygiene regulations. In addition, several swab samples were taken each day to assure the absence of surface contaminants. If any of the monitors or samples exceeded specified levels, the area would be evacuated and the operations suspended until appropriate action could be taken.

7. Operations

(a) Toxic operations began at the BZ facility at Pine Bluff in May 1988. The original operations concept, based on safety considerations, directed that the neat BZ should be processed first, followed by the M43 munitions, the M44 munitions, any disassembled munitions and submunitions, and finally the solid and liquid waste inventory. In addition to the inventoried BZ items, it was recognized that the liquid and solid wastes generated during the demilitarization/disposal activities would also have to be processed by

the plant during operations. Toxic operations were conducted for slightly over 21 months. Destruction of all the BZ and BZ-related materials was completed as follows: 242 drums of neat BZ, September 1988; 519 M43 Cluster Bombs, December 1988; 973 M44 Generator Clusters, June 1989; 78 disassembled M43s and M44s, September 1989; and 2,667 drums of both solid and liquid contaminated waste and scrap resulting from earlier production, storage and testing of BZ, January 1990.

(b) In addition to the inventoried BZ items, the plant was also required to process 5,964 drums containing approximately 90 pounds each of plant-generated waste. This waste was comprised of lab waste, wood from the shipping containers and pallets, decontamination solutions, contaminated clothing, rinse water, miscellaneous metal waste and the munitions casings. This waste was processed concurrently with the inventoried BZ material.

(c) In support of the plant, the laboratory was required to analyse between 40 to 120 samples per day. Laboratory personnel were also required to maintain the laboratory equipment and the plant and stack monitors to within the operating and quality control specifications. Each day plant operations were not allowed to begin until the laboratory could demonstrate that two separate analytical detection methods were in control and operable in the lab.

(d) Over 200 people were required to operate the BZ facility over the duration of the toxic campaigns. The plant personnel were required to complete an intensive training and testing program. The program consisted of a seven-step series of classroom, practical and operational training. The first five steps in the series qualified operators to operate the plant during non-toxic procedures. The final two steps certified operators to operate the plant during toxic operations.

(e) A large quantity of thermally decontaminated material resulted from the disposal of the BZ inventory. Demilitarization of the M43 and M44 munitions resulted in decontaminated metal parts, wood ash, and submunition bodies. Because the Army classified the munitions as Class B explosives, the BZ-filled munitions were classified as hazardous materials under the RCRA. The facility therefore was classified as a hazardous waste incinerator and was issued permits as such.

(f) The Army conducted a toxicity test of the char produced during BZ munition test burns at PBA. The results indicated that the material tested did not exhibit toxicity characteristic of hazardous waste and was free of any detectable BZ. In addition Caustic Methyl Cellosolve (CMC), the main

hazardous constituent in the BZ inventory of liquid drums, was also incinerated at PBA. The waste residue from this incineration was subjected to RCRA solid waste tests by the United States Army Environmental Hygiene Agency (USAEHA). This char also did not exhibit any RCRA hazardous conditions. Despite these findings, all the operational furnace residues and approximately 500 pounds of particulate and bagged particular material from the bag house were sent to the PBA RCRA hazardous waste landfill during the operation of the BZ facility.

8. Plant clean-up/demobilization

(a) The BZ facility at Pine Bluff was originally planned to be converted and used as part of the Chemical Stockpile Disposal Program (CSDP) plant to be built to demilitarize the unitary chemical stockpile at Pine Bluff upon completion of the demilitarization of the BZ inventory. Instead the final BZ facility closure implementation plan was predicated upon the dismantling, deactivating and in-place decommissioning of structures, waste management units, systems components and ancillary equipment to satisfy the RCRA permit. Thermal treatment (incineration) of selected items was employed in order to limit potential residual BZ contamination, to reduce landfill waste disposal volumes and to minimize the post-closure maintenance expenses and inventory.

(b) The intent of the closure activities and procedures was to remove only those equipment, components, structures and accessories from toxic areas that could not be decontaminated in place. Such items were removed and processed through the MPFs. The remaining equipment, components, structures and accessories located in toxic areas, were decontaminated in place to the level at which no surface contamination was present and certified clean by swab sampling. All wastes that were generated during the decontamination process were processed by established procedures. The status of the BZ demilitarization facility upon closure permits the United States Government to implement whatever planned future use, if any, it might envision within specified limits.

9. Overall program cost and chronology

The entire BZ inventory and all related material were demilitarized or disposed of, and the plant was decontaminated and decommissioned in June of 1990. The total program duration, from inception to conclusion, was 13 years and 11 months. The total cost for the program, excluding the cost of the

Office of the United States Army Program Manager for Chemical Demilitarization support, was $US 162.9 million. The BZ Program was broken down into eight major programmatic and cost elements. Each element is defined below:

(a) Process design/development

This element includes the costs from the program concept plan, laboratory development studies, process development studies and the equipment design charges. This element started with the BZ program conception in August of 1976 and ended when construction on the facility began in September of 1983. The cost for this element was $US 20.4 million.

(b) Construction

This element includes United States Army military construction funds to build the BZ facility. Construction began in August 1984 and ended in October 1986. The cost for this element was $US 8.8 million.

(c) Equipment acquisition/installation

This element covers the cost to purchase and install all the equipment in the BZ facility. Equipment installation began in July 1983 and was completed in January 1987. The cost for this element was $US 31.0 dollars.

(d) Systemization

This element encompasses all costs associated with the period between acceptance of the plant with functioning equipment, and the point at which toxic operations began. It includes testing of equipment to prove proper co-ordination operation, personnel training and testing, system interlock verification, monitoring equipment verification, laboratory certification, a short period of simulated operations, and a pre-operational survey with associated correctional costs. Systemization began in January of 1987 and was completed in March of 1988 at a cost of $US 26.6 million.

(e) Operations

This element includes all costs associated with the operation of the BZ demilitarization facility during toxic operations. Toxic operations began in May 1988 with the first shipment of bulk BZ and were concluded in January 1990 when the last item of BZ-related material in the BZ inventory was processed through the plant. This element cost $US 51.6 million to complete.

(f) Closure

This element covers the cost to decontaminate and demobilize the BZ facility after toxic operations. It includes the cost of removing and destroying any contaminated equipment and process waste, as well as the cost

to decontaminate and secure the facility. Closure operations began in January 1990 and were completed in June 1990 at a cost of $US 5.2 million.

(g) Depot support

A related additional cost to each of the above elements is the depot support cost. The depot support costs are the charges incurred for the PBA services rendered in support of the BZ program. These costs include personnel support for security safety, munitions transport, contract administration, utilities, and laundry services. The depot support costs began in 1980 and ran to the completion of the BZ program. The total depot support cost was $US 19.3 million.

FIGURE 1

BZ Demilitarization Program

Key Milestone Summary

Program assigned by Department of the Army (DA)	August 1976
Concept Plan approved by DA	August 1977
Laboratory (Phase I) support contract awarded to Battelle Columbus Laboratories	August 1978
Laboratory investigations of incineration and chemical neutralization completed	July 1979
Publication of exposure limits (Ideals)	January 1980
Laboratory investigations at PBA (incineration/ Detection Tests)	July 1980
Laboratory (Phase I) completed and process development (Phase II) begins	June 1981
Process development support contract awarded to Battelle Columbus Laboratories	September 1981
Munitions demonstrated to be non-detonatable	November 1981
FY84 construction design authority received	January 1982
Construction designer selected	June 1982
All major process development tests at PBA completed	June 1982
Construction concept design approved	February 1983
Process equipment acquisition contract awarded to Burns and Roe Industrial Service Corporation	July 1983
Construction and equipment designs completed	September 1983
Construction (Phase III) started	September 1983
Resourse Conservation and Recovery Act (RCRA) permit filed with State of Arkansas	September 1983
Air permit filed with State of Arkansas	December 1983

FIGURE 1 (continued)

Key Milestone Summary (Continued)

Safety site emissions approved	April 1984
Air permit issued by State of Arkansas	May 1984
RCRA permit issued by State of Arkansas	June 1984
Construction contract awarded to CWR, Inc.	August 1984
Equipment installation started	October 1985
Structural construction completed	October 1986
Equipment installation completed	January 1987
Systemization completed	March 1988
Preoperational survey completed	April 1988
Operations (Phase IV) started	May 1988
Destruction of neat BZ completed	September 1988
Destruction of M43 Cluster Bombs completed	December 1988
Destruction of M44 Generators completed	June 1989
Destruction of Disassembled M43 and M44 munitions completed	September 1989
Destruction of drummed solid material completed	September 1989
Destruction of drummed liquid material completed	January 1989
Plant clean-up and demobilization completed	June 1990

TABLE 1. BZ MUNITION & ITEM INVENTORY

MUNITIONS	QUANTITY Crated	Defused & Disassembled	Total
M43 Bomb Cluster	519	11	530
M44 Generator Cluster	973	37(a)	1010
NEAT BZ	**30-Gal Drums**	**QUANTITY**	**Total**
16-gal pails of neat BZ overpacked in 30-gal drums	242		242
ITEMS	**55-Gal Drums**	**QUANTITY 85-Gal Drums**	**Total**
Solid Residues(b)			
Ion-exchange resin	0	27	27
Sand	25	0	25
Filters	18	3	21
Insulation	31	0	31
Metal Parts from Refrigeration Equipment	111	0	111
Metal Parts from Disassembled Munitions	54	0	54
Wood	612	0	612
Miscellaneous Waste Materials (clothing, pipe, tools, etc)	109	20	129
	960	50	1010
Liquid Residues(b)			
CMC-water mixtures(c)	571	456	1027
Hydraulic oil	0	3	3
	571	459	1030

Other Residues

- 2 pallets plus 5 boxes of filters
- 5 storage pigs, boxed
- 1 box of reamed BZ-pyromix (545g)
- 1 wooden bulkhead
- 4 boxes of BZ lab samples
- 4 decon bath containers
- 1 roll packing material
- 8 smoke pot cans
- 6 metal bins with metal parts, tools, PVC pipe, etc. from building clean up.

(a) 25 M44s were dissassembled during previous test programs. An additional 12 M44s were disassembled following an igloo fire.

(b) PBA estimates that the cleanup of the BZ test igloo will generate an additional 200 drums of miscellaneous solids and 250 drums of CMC liquids.

(c) CMC is a mixture of 80 percent methyl cellosolve (see Appendix G), 10 percent NaOH and 10 percent water. The concentrations of CMC in the drums (i.e., the degree of dilution with water) is not known.

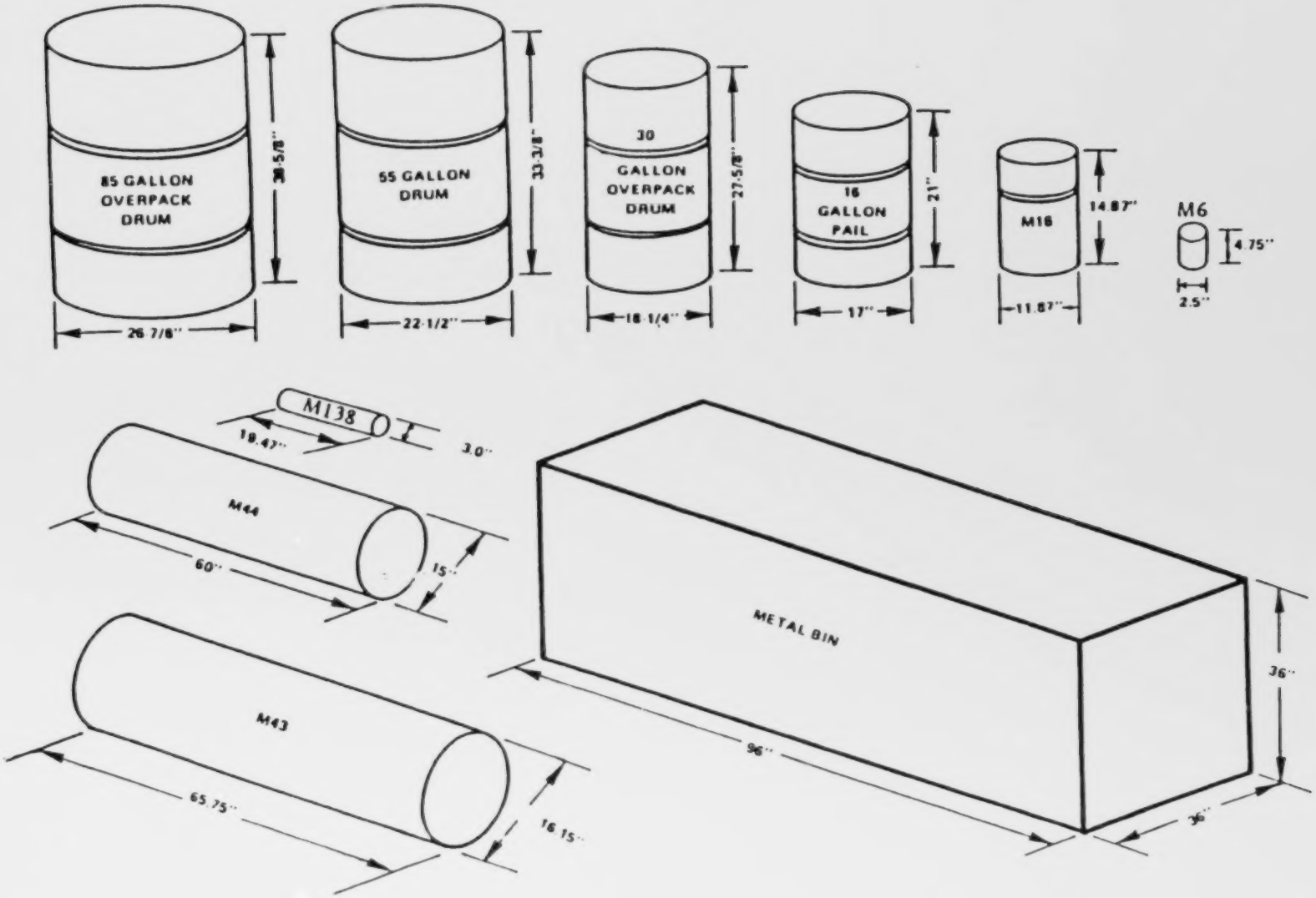
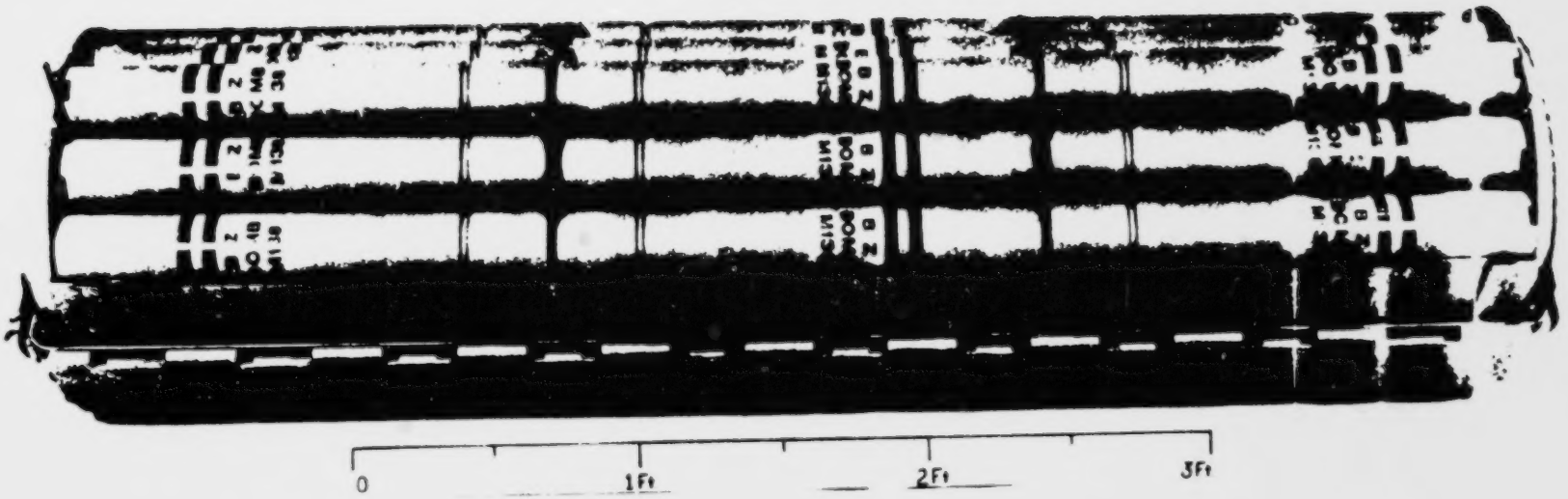
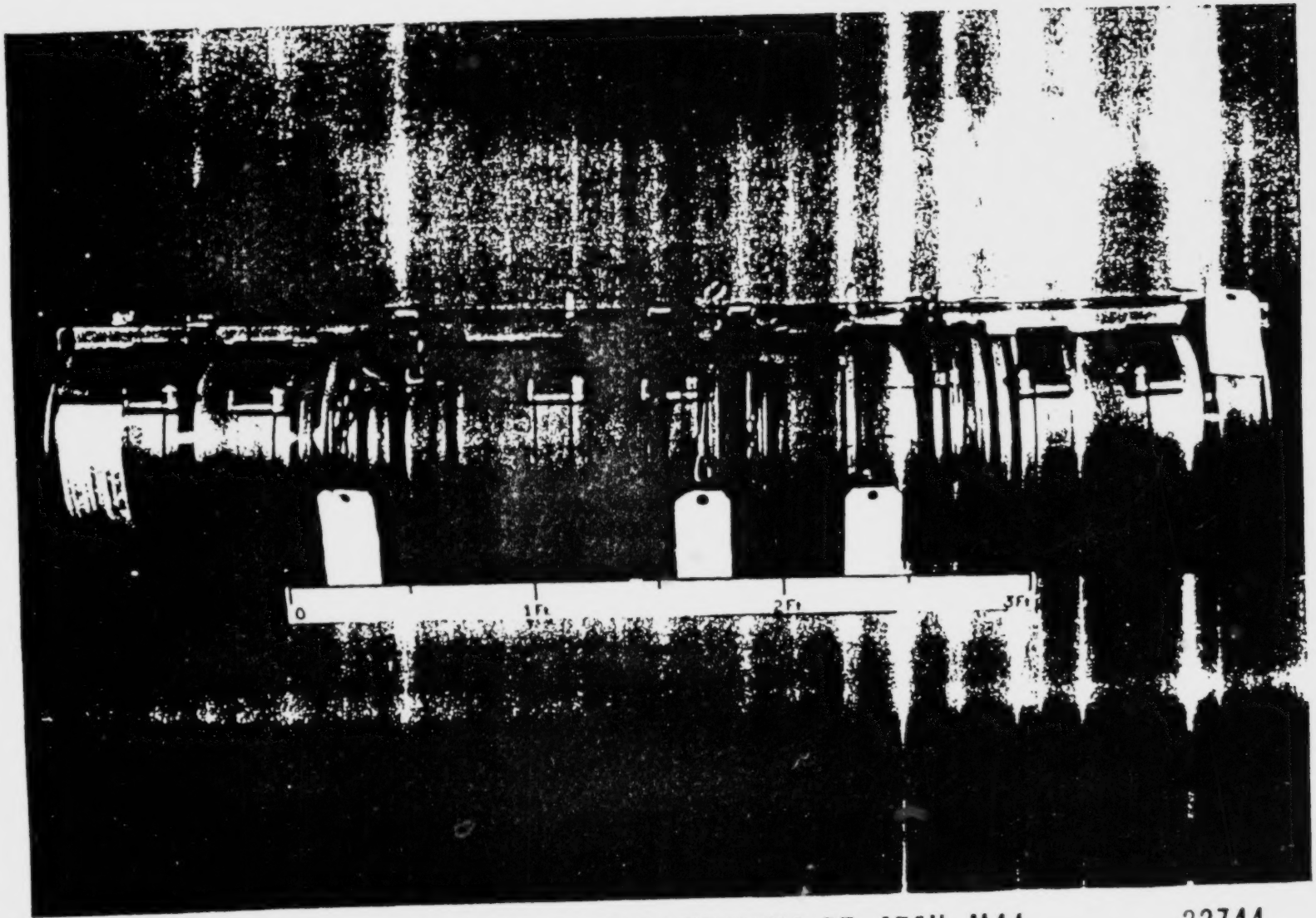


FIGURE 2 DIMENSIONS OF BZ-RELATED CONTAINERS



CLUSTER, BOMB, INCAPACITATING, BZ, 750-lb., M43

Figure 3



CLUSTER, GENERATOR INCAPACITATING BZ, 175lb M44 22744

Figure 4